

EL169867036

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

EL844047516

APPLICATION FOR LETTERS PATENT

706080 "2722660

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**Methods of Bonding First and Second Masses to
One Another, and Methods of Bonding Physical
Vapor Deposition Target Materials to Backing
Plate Materials**

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ATTORNEY'S DOCKET NO. HO57-002

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and Methods of Bonding Physical Vapor Deposition Target
Materials to Backing Plate Materials

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TECHNICAL FIELD

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The invention pertains to methods of bonding first and second masses to one another, and in particular embodiments, pertains to methods of bonding two similar materials together, as well as to methods of bonding physical vapor deposition target materials to backing plate materials.

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BACKGROUND OF THE INVENTION

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There are numerous applications in which it is desired to bond a first mass to a second mass. One such application is in the bonding of physical vapor deposition targets (such as, for example, sputtering targets) to backing plates. The backing plates are configured to retain the targets in particular locations and orientations within pressure vapor deposition apparatuses.

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Modern developments in physical vapor deposition methodologies have created increasingly stringent requirements for robust bonding between targets and backing plates. A diagrammatic view of a portion of an exemplary sputter deposition apparatus 10 is shown in Fig. 1. Apparatus 10 comprises a backing plate 12 having a sputtering target 14 bonded thereto. A semiconductive material wafer 16 is within

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1 apparatus 10 and provided to be spaced from target 14. Sputtered
2 material 18 is displaced from target 14 and utilized to form a coating
3 (not shown) over wafer 16.

4 Among the modern improvements in sputter design is an increase
5 in the distance between target 14 and semiconductive material
6 substrate 16. Such increase in distance can enable more directional
7 sputtering to be achieved over features of substrate 16 than can be
8 achieved when target 14 is close to substrate 16 by allowing atoms that
9 are not moving perpendicular to substrate 16 to land on the sidewall of
10 the sputtering chamber. Specifically, substrate 16 will frequently have
11 vertical holes or slots (known as vias) with depths five times their width
12 or more (i.e., having relatively high critical dimensions). It is difficult
13 to sputter materials into vias having high critical dimensions unless there
14 is a relatively long throw between a sputtering target and a substrate
15 comprising the vias.

16 Although the longer throw creates advantages in coverage relative
17 to shorter throw techniques, it also creates complications. One of such
18 complications is caused by additional power utilized in long-throw
19 technologies. The additional power can cause sputtering targets to get
20 hotter than they had in older methods. Such heat can disrupt a bond
21 formed between backing plate 12 and target 14. For instance, if
22 target 14 is solder-bonded to backing plate 12, the heat developed during
23 long-throw sputtering techniques can be sufficient to melt the solder

1 bond and actually break target 14 free from backing plate 12.
2 Accordingly, solder-bonding can be inappropriate for long-throw sputtering
3 techniques.

4 A type of bonding which is generally able to withstand the high
5 temperatures utilized in long-throw sputtering techniques is diffusion
6 bonding, which is a bond formed by solid state diffusion of components
7 from target 14 to backing plate 12 and/or vice versa. A difficulty in
8 using diffusion bonding is that such typically comprises relatively high
9 temperatures (300°C or more) to form the bond, and such temperatures
10 can adversely affect target materials. Accordingly, it can be difficult to
11 develop diffusion bonding processes for bonding physical vapor deposition
12 targets to backing plates, and which further retain desirable properties
13 of the physical vapor deposition targets. It would be desirable to
14 develop such diffusion bonding processes.

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16 **SUMMARY OF THE INVENTION**

17 In one aspect, the invention encompasses a method of bonding a
18 first mass to a second mass. A first mass of first material and a second
19 mass of second material are provided and joined in physical contact with
20 one another. The first and second masses are then diffusion bonded to
21 one another simultaneously with the development of grains of the second
22 material in the second mass. The diffusion bonding comprises solid state
23 diffusion between the first mass and the second mass. A predominate

1 portion of the developed grains in the second material have a maximum
2 dimension of less than 100 microns.

3 In another aspect, the invention encompasses a method of forming
4 a physical vapor deposition target bonded to a backing plate. A target
5 material and a backing plate material are joined in physical contact with
6 one another. The target material and backing plate material both
7 comprise aluminum. The joined target and backing plate materials are
8 thermally treated under an atmosphere which is inert relative to forming
9 oxides on the target and backing plate materials. The thermal treatment
10 simultaneously diffusion bonds the target material to the backing plate
11 material while recrystallizing grains in the target material. The diffusion
12 bonding comprises solid state diffusion between the backing plate
13 material and the target material to adhere the target material to the
14 backing plate material with a bond strength of at least 5,000
15 pounds/inch². A predominate portion of the grains developed in the
16 target material are less than 100 microns in maximum dimension after
17 the thermal treatment of the target and backing plate materials.

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19 **BRIEF DESCRIPTION OF THE DRAWINGS**

20 Preferred embodiments of the invention are described below with
21 reference to the following accompanying drawings.

22 Fig. 1 is a diagrammatic view of a portion of a prior art sputter
23 deposition apparatus.

1 Fig. 2 is a flow chart diagram of a method encompassed by the
2 present invention.

3 Fig. 3 is a diagrammatic illustration of a method of introducing
4 work hardening into a target material.

5 Fig. 4 is a diagrammatic illustration of the target material of
6 Fig. 3 with a backing plate at a preliminary bonding step.

7 Fig. 5 is a diagrammatic view of the target material and backing
8 plate of Fig. 4 at a bonding step subsequent to that of Fig. 4.

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10 **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

11 This disclosure of the invention is submitted in furtherance of the
12 constitutional purposes of the U.S. Patent Laws "to promote the progress
13 of science and useful arts" (Article 1, Section 8).

14 The invention encompasses methods of bonding materials to one
15 another, and in particular embodiments encompasses methods of bonding
16 a physical vapor deposition target material to a backing plate material.

17 One aspect of the invention is a recognition that it would be
18 advantageous to develop methodologies for diffusion bonding an
19 aluminum-containing target to an aluminum-containing backing plate,
20 while achieving relatively small grain sizes in the target material. A
21 difficulty associated with diffusion bonding of aluminum-containing targets
22 to aluminum-containing backing plates is that the diffusion-bonding
23 temperatures can cause growth of crystalline grains (actually

1 polycrystalline grains) in the aluminum targets. It is generally desired
2 that aluminum grains remain relatively small (i.e., less than 100 microns,
3 and more preferably less than 50 microns) in targets comprising high
4 purity aluminum (e.g., elemental aluminum), and aluminum alloys. The
5 smaller grains can improve sputtering processes in which aluminum is
6 sputtered from the target material relative to sputtering occurring from
7 a target material having larger grains.

8 The invention encompasses methodology for controlling grain growth
9 associated with the diffusion bonding of aluminum. Such methodology
10 can form a diffusion bonded aluminum sputtering target in which a
11 predominate portion of the grains in the target material have a maximum
12 grain size of less than 100 microns.

13 A method encompassed by the present invention is described by
14 a flow diagram in Fig. 2. At an initial step (labeled 30 in Fig. 2) work
15 hardening is done to the a target material. If, for example, the target
16 material comprises aluminum, work hardening can be introduced by
17 compressing the aluminum from an initial thickness to a second
18 thickness. Such compression is illustrated in Fig. 3, wherein a target 50
19 is illustrated before and after compression, with an arrow 52 provided
20 to indicate the step of compression. Target 50 comprises a first
21 thickness "X" prior to the compression 52 and a second thickness "Y"
22 after the compression. The compression can be accomplished by, for
23 example, cold forging or cold rolling. The final thickness of target 50

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1 ("Y") can be, for example, less than 2% of the initial thickness of target
2 50 (i.e., a 98% compression), and is typically less than or equal to about
3 40% of the initial thickness of target 50 (i.e., a 60% compression). In
4 particular embodiments, target 50 can be subjected to a 95% compression
5 (i.e., compressed so that final thickness "Y" is about 5% of initial
6 thickness "X").

7 Target 50 can, for example, comprise or consist essentially of low
8 to high purity aluminum. An exemplary commercial (low-purity)
9 aluminum that can be utilized for target 50 is 1100 series aluminum
10 alloy. The material of target 50 can be cast as a billet having a
11 diameter of from about 4 inches to about 9 inches, and having an initial
12 thickness of from about 5 inches to about 10 inches. After the
13 compression of target 50, the resulting cold-worked blank can be cut to
14 form a round blank of a desired diameter.

15 Referring again to the flow chart of Fig. 2, the target is joined
16 to a backing plate (Fig. 2, step 32). Preferably, the target and backing
17 plate are cleaned prior to joining them to remove contaminants that may
18 be present. A method of joining a target to a backing plate is
19 described with reference to Figs. 4 and 5. Referring to Fig. 4, the
20 work-hardened target 50 of Fig. 3 is shown elevated above a backing
21 plate 60. Backing plate 60 of Fig. 3 is shown having a continuous
22 channel 62 machined into a surface in a spiral pattern. Ultimately,
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1 target 50 will be pressed against plate 60 to force material from
2 target 50 into channel 62.

3 In embodiments in which target 50 comprises high-purity aluminum,
4 backing plate 60 can also comprise aluminum, and can specifically
5 comprise, for example, 2000 Series, 5000 Series, 6000 Series or 7000
6 Series heat-treatable aluminum alloys. In particular embodiments, backing
7 plate 60 can comprise heat-treatable aluminum alloy 6061 in either a T4
8 or T6 precipitate hardened condition.

9 An initial step in bonding target 50 to backing plate 60 is typically
10 to join the target and backing plate by physically contact target 50 with
11 plate 60. Arrows 54 of Fig. 4 indicate such joining by showing that
12 target 50 is lowered onto plate 60. Fig. 5 shows an assembly 70
13 comprising target 50 joined to plate 60. In the shown assembly 70,
14 target 50 covers channel 62 (Fig. 4) of backing plate 60. Although the
15 shown embodiment has a channel formed in backing plate 60 to enhance
16 coupling of target 50 to backing plate 60, it is to be understood that
17 such channel can be eliminated in particular embodiments of the
18 invention, or can be provided in target 50, rather than in backing
19 plate 60. In embodiments in which one of backing plate 60 and
20 target 50 is harder than another of backing plate 60 and target 50,
21 channel 62 will preferably be provided in the harder of the two, so that
22 the softer of the two can be pressed into the channel in subsequent
23 processing.

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Assembly 70 is can be formed in, or placed in, an atmosphere which is inert relative to oxide formation from materials of plate 60 and target 50. In embodiments in which plate 60 and target 50 comprise high-purity aluminum, or aluminum alloys, the inert atmosphere can comprise a vacuum, or consist essentially of, for example, one or more of nitrogen gas and argon gas. The inert atmosphere preferably does not comprise oxidative components (like oxygen), as such could adversely cause oxidation of the materials of one or both of the blank 60 and target 50.

Referring again to the flow chart of Fig. 2, the joined backing plate and target are thermally treated (step 34 of Fig. 2) to simultaneously 1) diffusion bond the target to the backing plate, and 2) develop grains in the target. If target 50 and backing plate 60 comprise high-purity aluminum, the thermal treatment can comprise, for example, heating the joined target and backing plate to a temperature of between 280°C and 400°C (preferably between 300°C and 340°C), and maintaining such temperature for a time of from about 15 minutes to about an hour. During the time that the temperature is maintained, target 50 and backing plate 60 can be compressed in a forge to pressure of from about 10,000 pounds per square inch (psi) to about 16,000 psi.

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An exemplary thermal treatment procedure for treating a target and backing plate which comprise aluminum is as follows. Initially, an assembly comprising a target joined against a backing plate is heated to

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1 a temperature of from about 280°C to about 400°C (preferably from
2 about 300°C to about 350°C, and more preferably from about 300°C to
3 about 344°C) and maintained at such temperature for a time of from 15
4 to 30 minutes. The assembly is then transferred to a forge which is
5 also maintained at a temperature of from about 280°C to about 400°C.
6 The forge is utilized to compress target 50 and backing plate 60 together
7 to a temperature of from about 10,000 psi to about 16,000 psi. After
8 compressing the target and backing plate, the assembly is transferred
9 back to the furnace having a temperature of from about 280°C to about
10 400°C, and maintained at such temperature for an additional time of
11 from about 10 minutes to about 30 minutes.

12 The above-described exemplary method allows diffusion bonding
13 (specifically, solid state diffusion of aluminum between target 50 and
14 backing plate 60), as well as development of grains within target 50.
15 Such grains form due to cold work introduced in target 50 during the
16 compression of Fig. 3. The grain development typically involves three
17 distinct steps. First, recovery in which stresses are relieved from in the
18 most severely deformed regions. Second, the cold-worked grains
19 recrystallize forming small, new, stress-free grains in target 50, and finally
20 grain growth of the new grains occurs. Preferably, target 50 is not
21 exposed to a temperature above about 280°C from the time it is work-
22 hardened in the step of Fig. 3, until it is exposed to the thermal
23 treatment. Accordingly, substantially an entirety of the grain

1 development of target 50 occurs during the thermal treatment of
2 target 50 and backing plate 60. The phrase "substantial entirety" is
3 utilized in referring to the recrystallization and grain growth occurring
4 during the thermal treatment, rather than stating an "entirety" of the
5 recrystallization and grain growth to indicate that there may be a small
6 and effectively inconsequential amount of recrystallization and grain
7 growth occurring at temperatures below 280°C during processing and
8 cleaning of target 50 prior to the thermal treatment.

9 A particular process for accomplishing the above-discussed thermal
10 treatment method is to place the assembly of the target and backing
11 plate in a can (for instance, a can made of thin-walled aluminum), and
12 to retain the assembly in the can during the heating and forging (i.e.,
13 pressing) associated with the diffusion bonding. The can preferably
14 comprises two parts, and a wide flange which allows for subsequent
15 welding to seal the target and backing plate assembly in the can. Also,
16 the can preferably has a small diameter tube which allows for vacuum
17 checking of a weld seal on the can, as well as for providing a vacuum
18 or inert atmosphere inside the can. Once the target and backing plate
19 assembly is provided in the can, the can is welded shut. An inert gas
20 or vacuum can be utilized during the welding to alleviate oxidation of
21 the target and backing plate assembly. Weld integrity can be determined
22 by conducting a leak test using the small diameter tube. A final weld
23 can be done on the small diameter tube to allow a vacuum or inert gas

1 atmosphere to be maintained in the can. During the time that the
2 target and backing plate assembly is subjected to diffusion bonding, a
3 temperature of the assembly can be monitored indirectly by monitoring
4 the temperature of a so-called dummy part having the same dimensions
5 as the target and backing plate assembly, and heated in either the same
6 furnace as the assembly, or in an identical furnace.

7 After the thermal treatment of the target and backing plate
8 assembly, such assembly is cooled. The cooling can be accomplished by
9 exposing the assembly to either a liquid or a gas, with an exemplary
10 liquid being water, and an exemplary gas being air.

The methods discussed above can form a target and backing plate assembly 70 comprising a strong diffusion bond between target 50 and backing plate 60, with a tensile strength of such bond being at least 5,000 psi, and typically being between about 8,000 psi and 10,000 psi. The yield strength of fully recrystallized high purity aluminum is 3,000 psi, which is about equivalent to 20 megapascals (MPa) and the ultimate tensile strength is 12 ksi (81 MPa). The yield strength of 6061 T4 is 21 ksi (145 MPa), and the ultimate tensile strength of 6061 T4 is approximately 35 ksi (241 MPa).

20 The diffusion bond can have a strength close to that of the
21 ultimate tensile strength of high purity aluminum, with the bond
22 frequently having a strength of from about 68.5% to about 83% of the
23 tensile strength of the high purity aluminum utilized in the target

1 (typically from about 8230 psi to about 9948 psi at room temperature).

2 In contrast, solder bonds typically have strength ranges from about 1470
3 psi to about 6740 psi. Bonds formed by methods of the present
4 invention can therefore be significantly stronger than solder bonds, and
5 accordingly, better suited for the long-throw target applications of modern
6 sputtering applications that were discussed in the "Background" section
7 of this disclosure.

8 The backing plate preferably remains strong after the above-
9 discussed diffusion bonding. In a particular embodiment, a 6061 backing
10 plate was found to retain a minimum strength equal to 6061-T4 when
11 subjected to diffusion bonding at a temperature of about 300°C.

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13 In addition to the strong bond formed between target 50 and
14 backing plate 60 of assembly 70, a grain size of target 50 is preferably
15 below 100 microns, more preferably from about 30 to less
16 than 100 microns, and more preferably below about 50 microns after the
17 diffusion bonding. Specifically, a predominate (i.e., more than 50%) of
18 the grains in target 50 will preferably have a maximum dimension of less
19 than 100 microns, more preferably from about 30 microns to less
20 than 100 microns, and more preferably less than about 50 microns. In
21 particular embodiments, an entirety of the grains in target 50 have a
22 maximum dimension of less than 100 microns, more preferably from
23 about 30 microns to less than 100 microns, and more preferably less
than about 50 microns.

1 The above-discussed small grain size can be accomplished by
2 starting with a target which been cold-worked, but which does not have
3 grains formed. Accordingly, a recrystallization process will occur in the
4 target material prior to growth of grains. For aluminum, such
5 recrystallization process typically takes from about 20 to 30 minutes at
6 a temperature of between 288°C and about 316°C. Thus, a target will
7 spend a significant amount of time that it is at a diffusion bonding
8 temperature in a stage where grains are recrystallizing, rather than
9 growing. Such can prevent the grains from over-growing during the
10 diffusion bonding to sizes that are, for example, in excess of
11 100 microns.

12 Experiments have been performed to determine if increases in
13 processing temperatures or times improve bonding of targets to backing
14 plates. It is found that if a target is treated with higher temperatures
15 or longer times, dramatic increases in grain size can occur, but only
16 minor increases in bond strength are found.

17 It is to be understood that although several of the particular
18 aspects described above pertain to first and second masses comprising
19 aluminum, the invention can be utilized with masses other than those
20 comprising aluminum. It is preferred that the masses comprise a
21 component in common to enable diffusion bonding between the masses.
22 Specifically, if the masses comprise a component in common, then the
23 component can diffuse as a solid from one of the masses to another of

1 the masses. The first and second masses can also comprise no common
2 components, but diffusion between materials having the same component
3 (known as self-diffusion) is typically faster than diffusion between
4 materials comprising only dissimilar components. In particular
5 embodiments, the masses will comprise an element in common, such as,
6 for example, elemental aluminum.

7 In compliance with the statute, the invention has been described
8 in language more or less specific as to structural and methodical
9 features. It is to be understood, however, that the invention is not
10 limited to the specific features shown and described, since the means
11 herein disclosed comprise preferred forms of putting the invention into
12 effect. The invention is, therefore, claimed in any of its forms or
13 modifications within the proper scope of the appended claims
14 appropriately interpreted in accordance with the doctrine of equivalents.

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